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Environmental Sensing and Forest Degradation Using Mono-Temporal Analyses of Logging Roads

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Abstract

Forest degradation is the reduction of the forest capacity to provide and produce ecosystem services such as forest, wood products and carbon storage which are caused as a result of adverse environment and anthropogenic changes. Various human and natural activities do cause degradation, that include agricultural practices, fire, fuel wood, livestock rearing, invasive plant species and unsustainable logging practices. The assessment of forest degradation is focused on forest management regimes, climate change and impact on biodiversity. Forest degradation in a small area of Congo Brazzivilla(3km x 3km) was evaluated based on the cause, exploitation of forest resources and services under the use of remote sensing technology considering temporal and spatial scales. Ground truth data was utilized using the GPS points and data were observed and collected in such a way that the various land use and land cover changes in the area were well represented. Initial and preliminary analysis of multi-temporal RADARSAT (MF22F) optical data of high resolution optical images was used in this study, namely WorldView-2 and QuickBird. SAR Data was applied using Radar wavelengths, which are classified into six bands: K-band (1cm), X-band (3cm), C-band (5.6cm), S-band (10cm), L-band (23cm) and P-band (75cm).

Small wavelengths (X and K) have low penetration capability; as such they are majorly reflected by the branches of forest trees. Mono-temporal delineation of forest degradation signs in WorldView-2 image and QuickBird image application were conducted using the WorldView-2 image that was visually interpreted. The forest vegetation appeared in red. Bright features opened up gaps into the forest canopies. The logging roads on the TerraSAR are faintly visible. They appear as small stripe features, corresponding to the logging road line shapefiles of the optical images that were overlaid on them. It is therefore identified and observed that forest degradation does decline provision of ecosystem services from primary forests. Degradation, loss of ecosystem services and unsustainable forest management has corresponding effect on productivity, biodiversity, unusual disturbances, protective functions and carbon storage. This study therefore suggests the need to assess and determine forest degradation at both regional and national scales.

Keywords

Remote Sensing, Congo-Brazzaville, Forest Degradation; Forest Management, RADARSAT, WorldView-2 and QuickBird

Introduction

Forest degradation and deforestation has been identified as a critical issue and both account for appreciable percentage of the total annual anthropogenic greenhouse gas (GHG) global emissions. It has been observed that most of these emissions occur in tropical countries. Recent climate negotiations have initiated the concept of reducing emissions from deforestation and forest degradation (REDD) to mitigate climate change through forest management, including the restoration of degraded forests [1]. Deforestation is an obvious ecosystem change, but forest degradation is more difficult to discern and quantify [2]. Abatement of tropical deforestation and forest degradation offers an opportunity for mitigating global warming that has become a crucial and an integral part of global climate change negotiations driven by the United Nations Framework Convention on Climate Change (UNFCCC). Various frameworks and policy have been formulated by the international community to restore and minimize forest degradation whereby a restoration target of about 15% of degraded ecosystems by 2020 [3]. Furthermore, global efforts have been put in place such as UN Forum on forests that has an objective to reduce

degradation; the UN Convention to Combat Desertification (UNCCD) that considers degradation on dry lands; and the UN Framework Convention on Climate Change (UNFCCC) that proposes to recover degraded forests as carbon sinks. The Kyoto Protocol of the UNFCCC evolved in 1997 is responsible for committing industrialized countries to ensure quantified reduction targets of GHG emissions [4]. In furtherance to this commitment, the 13th Conference of Parties (COP-13) of the UNFCCC in 2007, the Bali Action Plan highlighted the importance of policy approaches and positive incentives on Reducing Emissions from Deforestation and Forest Degradation (REDD) [5]. REDD is an international effort to create a financial value for the carbon stored in forests. It aims at offering incentives to developing countries to preserve their national and community forests with regards to climate change mitigation (UNFCCC, 2012). REDD+ is a new global partnership between developing and developed countries through which low-carbon land use strategies are developed and adopted to minimize deforestation and forest degradation; whereby all these aims at promoting forest conservation and sustainable forest management [6]. Developing countries would be paid by developed countries for the service of avoided deforestation and degradation under this mechanism. Therefore, REDD+ goes beyond reducing deforestation and forest degradation to include forest conservation and sustainable forest management [7]. This assessment is in line with various global efforts and background to minimize forest degradation and forest deforestation. This assessment and study objective was based on forest degradation from a remote sensing imagery acquired from very high resolution SAR (1m TerraSAR-X High-Resolution SpotLight and 3m TerraSAR-X StripMap imagery) in a small area in Congo – Brazzaville and as well evaluates the environmental sensing and attributes of forest degradation. This will provide mono-temporal analysis of forest gaps, logging roads and other signs of forest degradation from WorldView-2. Degraded forests in Congo-Brazzaville can be traced to several decades of over harvesting of timber, shorter fallow periods in shifting cultivation, and deliberate burning.Sensing in a simple definition means to detect, perceive, or become aware of some phenomena external to us. Remote sensing technology has long been identified as a means of detecting or perceiving phenomena where the measurements taken at distance from objects and surfaces of interest are transformed into information, in a manner analogous to human brain transforming the perception of touch into concepts such as rough or smooth. For the purpose of this assessment, environmental remote sensing may be defined as the measurement and representation of earth surface characteristics that support the information requirements for effective environmental management and decision making. This practical definition suggests that there is an underlying rational that directs the remote collection of data and narrows the scope of the science of remote sensing by focusing on the delivery on information that illuminates the complexities, uncertainties and dynamic nature of the environmental process. In this regard, environmental remote sensing is an extension of an existing technique that strives to incorporate alternative strategies and sensors that can yield new information and provide new insight into the status of earth's environments and detect conditions of critical concern.

Environmental sensing and attributes of forest degradation overtime have attracted various methods of assessing forest degradation that include: a). Optical remote sensing for forest degradation studies which applies to Normalized Difference Fraction Index (NDFI) to detect logging and fire scars. The NDFI combines the information of several component fractions of images defined by Spectral Mixture Analysis (SMA).[8] and[9] developed and applied the Carnegie Landsat Analysis System (CLAS) to map forest degradation and deforestation. b). Radar remote sensing for forest degradation where Radar is an active sensor, which means that it generates its own source of energy in a beam that is incident upon an imaging feature on the earth surface. From the imaging object on the earth surface, the radar sensor then receives and records the reflected energy called backscatter or return signal in sequence. Radar systems use wavelength ranging from about 1cm to 1m [10]. The use of these wavelengths gives radar systems two distinct advantages over the visible and infrared multispectral optical system: one is that they can penetrate cloud and haze; and the second is that they can image objects on the earth surface irrespective of whether it is day or night. However, the lack of an agreed common definition (and monitoring framework) hinders international recovery efforts [11]. The recently completed *Global Forest Resources Assessment* [12] could not report an area of degraded forest for lack of a definition. However, it means there is no effective methods to map and monitor changes resulting from forest degradation process. Hence, this raises the question of whether it is feasible to include forest degradation into the MRV agenda of REDD+. Non-inclusion of the forest degradation process in the MRV framework could limit the effective realization of the core-objective of REDD+; because focusing only on deforestation can lead to forest carbon leakages. Generally, it has been observed that land

and forest degradation indicates both temporary and permanent long-term decline in ecosystem function and productivity capacity. The key problem envisaged in this study is that the deterioration and destruction in health of terrestrial ecosystems which affects associated biodiversity, natural ecological processes and ecosystem resilience.

Description of Study Area

Youbi, Kouilou, Congo- Brazzaville (Table 1 and Figure 1) is the study site selected and for the implementation of the EU REDDiness project by the project partners on mapping forest degradation in Congo and Gabon with satellite imagery [13]. It is situated on 4°11′24″ S and 11°40′4.0″E with elevation of 39m [14]. It is situated 74km north-west of Pointe-Noire close to Brazzaville. Youbi encompasses the Sud Forest Management Unit in the district of Madingo-Kayes and has a very low human population density of 1.4 persons per km[2]. A more general vegetation types for Congo-Brazzaville are summarized in Table 1 [15]. This study focuses on a small area of 20km x 10km to evaluate the potential of SAR imagery to directly detect signs of forest degradation [16].

TABLE 1: AVERAGE BIOMASS OF VEGETATION TYPES IN THE STUDY REGION

Land cover type	Mean biomass (Mg/ha
Swamp forest	251.0
Mosaic forest/savannah	77.4
Closed evergreen lowland forest	216.3
Deciduous woodland	35.2
Open grassland with sparse shrubs	1.0
Croplands (>50%)	5.3
Sub-montane forest (900-1500m)	238.1

Baccini et al., 2008

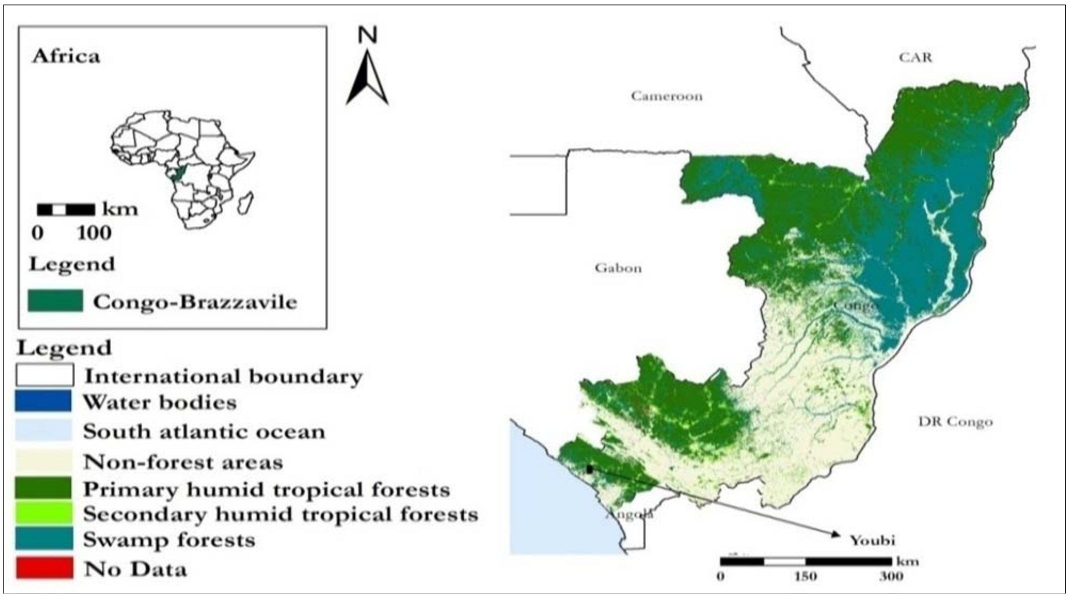

FIG 1: LANDCOVER MAP OF CONGO- BRAZZAVILLE SHOWING THE STUDY REGION YOUBI; MODIFIED FROM (CARPE, 2010)

Ground Truth Data

The GPS points (geo-referenced data) and illustrative pictures were collected within the period: 26 August – 4 September, 2012. These data were observed and collected in such a way that the various land use and land cover changes in the area were well represented. Before the field mission, a number of points were provided as such they were partly derived from preliminary analysis of multi-temporal RADARSAT (MF22F) data. The pre-field analyses of reference points, was done by the faculty ITC. After the fieldwork, a total of thirty-eight geo-referenced points were collected for the study area of Youbi, Congo-Brazzaville (Figure 1).These field data were further used in this study to assist in the visual interpretation of both the optical and SAR satellite images.

Optical Data

Two very high resolution optical images were used in this study, namely WorldView-2 and QuickBird. Both were provided by DigitalGlobe, Incorporated (http://www.digitalglobe.com) and obtained for the REDDiness project through the GMES Data Access Portfolio. The Worldview-2 image consists of one panchromatic band at 0.5m resolution and eight multi-spectral bands at 2.0m resolution. The image was taken on the 29th of August, 2011. This image was provided as a geometrically-corrected product, registered to the WGS 84 datum and the Universal Transverse Mercator (UTM) zone 32S projection. The QuickBird image has one panchromatic band and four multispectral bands with a spatial resolution of 0.6m and 2.4 m at nadir respectively. The image was taken on the 27th of July; 2012.Figure 1 shows the optical images used in this study as well as the GPS points collected at the study site.

Synthetic Aperture Radar (SAR) Data

Radar wavelengths are classified into six bands: K-band (1cm), X-band (3cm), C-band (5.6cm), S-band (10cm), L-band (23cm) and P-band (75cm) (University of California). Small wavelengths (X and K) have low penetration capability; as such they are majorly reflected by the branches of forest trees [17]. Available for this study were Synthetic Aperture Radar (SAR) images which were obtained from three different platforms, namely TerraSAR (3cm wavelength), RADARSAT-2 (~6cm wavelength) and ENVISAT (~6cm wavelength). The images were acquired for the REDDiness project through the GMES Data Access Portfolio. The image data set includes archive data, whereas within REDDiness a number of new acquisitions were requested to create multi-temporal data-sets (Figure 2), and to have a high-resolution coverage of the study site. Two modes of TerraSAR acquisition (at X-band) were used. These include the SpotLight mode (HS300) at 1m resolution; and the StripMap mode at 3m resolution. To obtain an approximately full coverage of the study sites, five TerraSAR-X SpotLight images were acquired over the study site between 25 February and 20 April 2012. The SpotLight mosaic has a pixel spacing of 0.5m. The two StripMapTerraSAR-X images were acquired on 9 June 2010 and 1 May 2012. All TerraSAR-X data are acquired in a Horizontal-send, Horizontal-receive (HH) mode. For RADARSAT-2, Multi-look Fine imagery was used with two different incidence angles, named MF22F and MF6.MF22F has an incidence angle of 34.8° and was acquired during ascending orbits on 4 March in 2012. MF6 has an incidence angle of 48.1° and was acquired during descending orbits on 1 April in 2012. Both MF22F and MF6 have a spatial resolution of 8m and a pixel size of approximately 3m; and were acquired in a Horizontal-send, Horizontal-receive polarization. An image mode of ENVISAT with VV polarization was used in this study. The ENVISAT image was acquired on 18 March, 2012 at an incidence angle of 23°. The image has a spatial resolution of 30m and a pixel size of 12.5m.

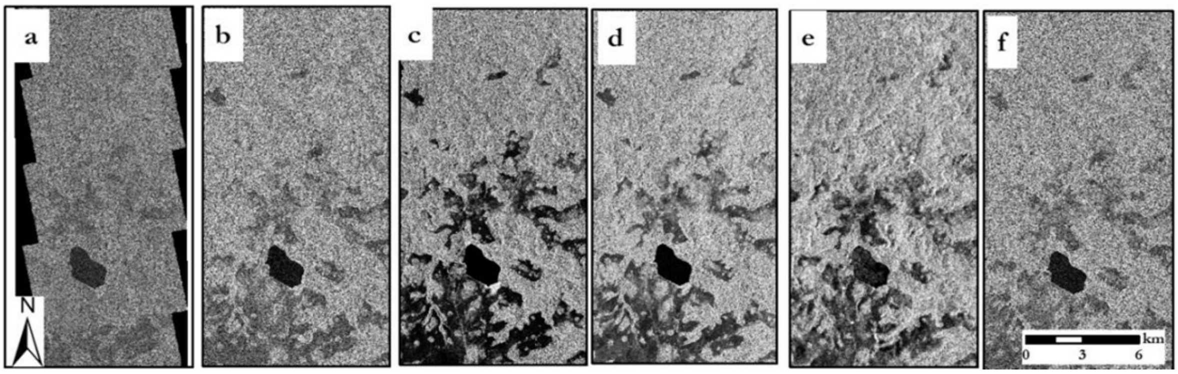

FIG 1: OVERVIEW OF SAR DATA THAT WERE AVAILABLE FOR REDDINESS PROJECT, A) TERRASAR-X SPOTLIGHT OF FEBRUARY-APRIL 2012 IMAGE; B) TERRASAR-X STRIPMAP IMAGE OF MAY 2012; C) RADARSAT MULTI-LOOK FINE IMAGE OF AT 34.8° (MF22); D) RADARSAT MULTI-LOOK FINE (MF6) IMAGE AT 48.1°; E) ENVISAT ASAR VV IMAGE OF 2012; AND F) TERRASAR-X STRIPMAP IMAGE OF JUNE 2010

Mono-Temporal Delineation of Forest Degradation Signs in Worldview-2 Image and Quickbird Image

First, the WorldView-2 image was visually interpreted. The forest vegetation appeared in red. Bright features opened up gaps into the forest canopies. These degradation features were separately digitized into polylines and polygons respectively, using the editor toolbox of ArcMap. The digitized features were afterwards, saved as shapefiles. Digitization of logging road line feature was done in segments, because, it was not possible to observe a

continuous logging road running through the study area. This segmentation of logging roads was facilitated by clouds and tree crown covers. Afterwards, specific attribute fields were added to the attribute tables of the digitized logging roads and clearcuts of each optical image. For logging road line shapefile: descriptions, length (m), width (m), XY mid-length coordinates (m) and angle of orientation (degrees); were added. Angle of orientation was added because; it is an important parameter for SAR data. This is because, radar backscatter is sensitive to an orientation of ground features, depending on the viewing direction of radar sensor (University of California). For clearcut polygon shapefiles, fields such as: description, area (m^2), area (ha), and their XY coordinates at centroid; were added to their shapefiles in the attribute table. These attribute fields were used to calculate the length and width (logging road segment), area (clearcut) and actual geographical location in ArcGIS. A map of logging roads and clearcuts was produced from the WorldView-2 image. To detect changes between 2011 and 2012, the pan-sharpened QuickBird image (2012) was also displayed side by side with that of the WorldView-2 image. The shapefiles of the logging roads and clearcuts from the WorldView-2 image were then overlaid onto the Quickbird image, for a comparative visual analysis between them. Based on observation, new logging road and clearcutshapefiles werecreated on the QuickBird image. Their respective attribute fields (as expressed in the above preceding paragraph), were added to the line and polygon features digitized on the QuickBird. These attribute fields on QuickBird image were uniquely named so as to differentiate them from those of the WorldView-2 image. Logging road line feature and clearcut polygon feature maps were produced as outputs from this visual analysis on the QuickBird image.

Research Findings on Mono-Temporal Analyses of Logging Roads

The small area of 3km x 3km sampled within a smooth canopied forest on the WorldView-2 image where the subset is located east of the main road (10 wide) that runs through the study area. There are pockets of cloud covering some portion of the subset on the Worldview-2 image. The QuickBird image (not shown) has a less amount of cloud at this subset location. While there were large numbers of logging roads observed on the WorldView-2, only seven could be seen for this small area on the QuickBird image (not shown).While on the 1m TerraSAR-X SpotLight image (Figure 3c), a total of 20 logging roads are visible within this subset, most of which (except for one) could also be observed from 3m TerraSAR-X StripMap (Figure 3b). The logging roads on the TerraSAR are faintly visible. They appear as small stripe features, corresponding to the logging road line shapefiles of the optical images that were overlaid on them. None of the logging roads could however be observed on RADARSAT Multi-Look Fine imagery (for both incidence angles).These RADARSAT data (Figure 3f) have smoother forest canopy than on the two TerraSAR images.

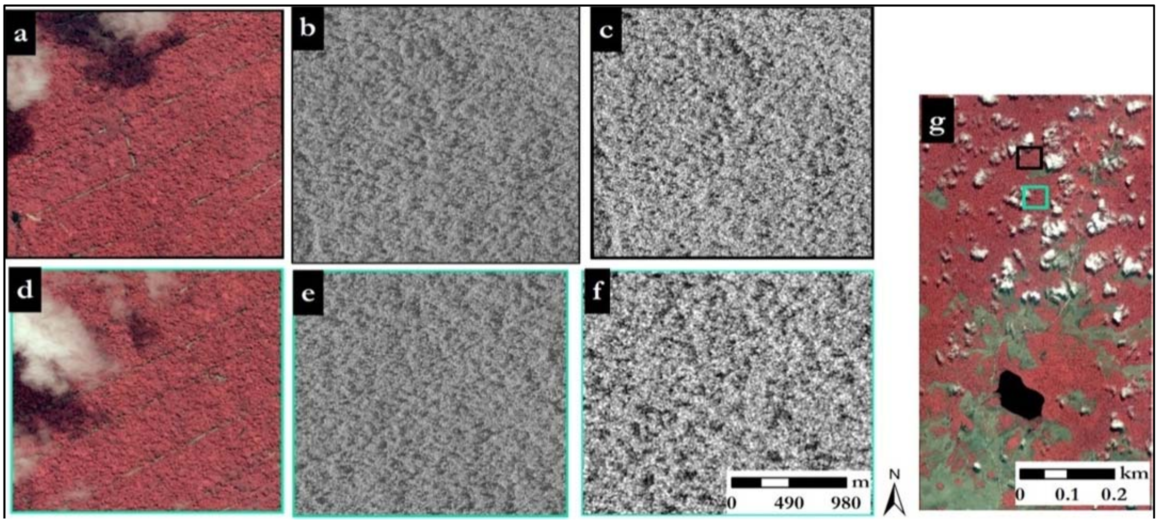

FIG: 3 IMAGE SUBSET THAT SHOWS SOME LOGGING ROADS (8.5M WIDE): A) WORLDVIEW-2 IMAGE, B) 3M TERRASAR-X STRIPMAP IMAGE - 1 MAY 2012 WITH INCIDENCE ANGLE OF 37.8O, C) 1M MOSAIC TERRASAR-X SPOTLIGHT – 7 AND 18 MARCH 2012 BOTH INCIDENT AT 39O, D) 8M RADARSAT MULTI-LOOK FINE IMAGE – 4 MARCH 2012 AT INCIDENCE ANGLE OF 34.8O, E) 8M RADARSAT MULTI-LOOK FINE – 1 APRIL 2012 INCIDENT AT 48.1O, AND F) WORLDVIEW-2 SHOWING 3KM X 3KM SUBSET IN BLACK BOX.

Further results of virtual analyses on two image subsets measuring 1000 x 1000m each shows that these two image subsets are located to north on the WorldView-2 image; and situated at the west of the main road crossing the

study area. Each image subset are less clouded but with lots of logging road features on the WorldView-2 image. These logging roads are almost invisible on the QuickBird image (not shown). Figure 4(a-c), correspond to the black box on the WorldView-2 overview image (Figure 4g). This location is cloud-free on the QuickBird image. The results of the other image subset (figure 4f) correspond to the location in the cyan box on Figure 4g. It has lesser cloud on the QuickBird image.

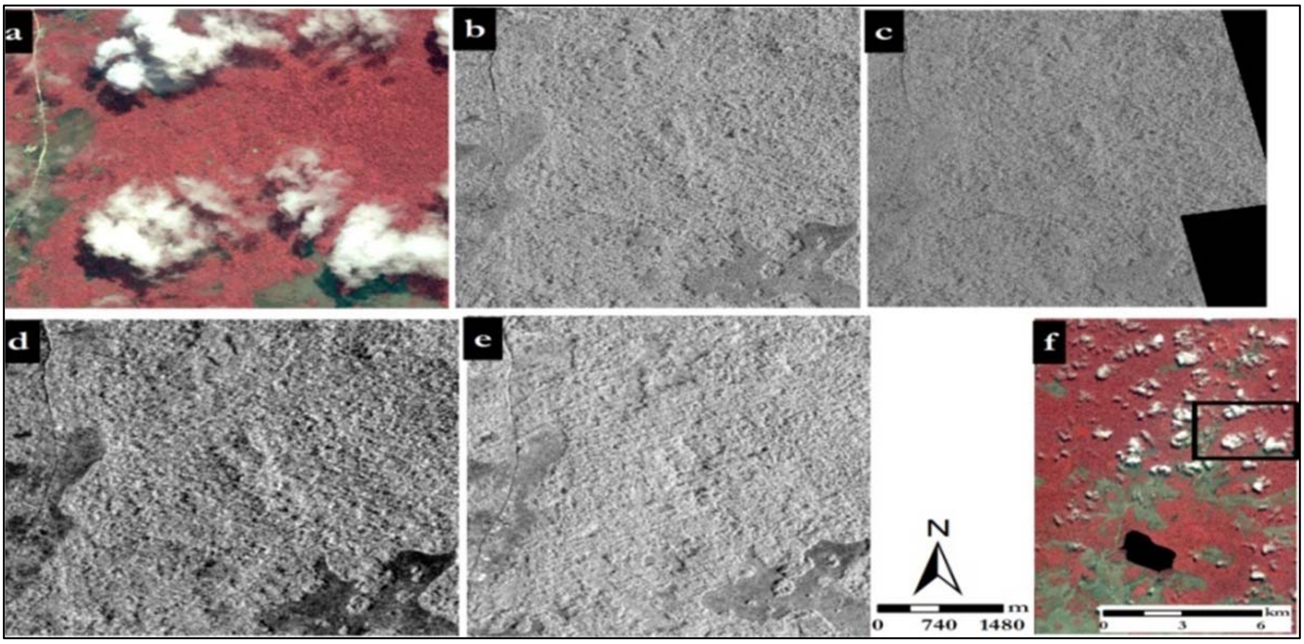

FIG 4: DETECTION OF LOGGING ROADS AT A COARSE CANOPY FOREST. IMAGES TESTED AT SITE ONE INCLUDES: A) WORLDVIEW-2 IMAGE, B) 1M TERRASAR-X SPOTLIGHT OF MARCH 7 2012 AND C) 3M TERRASAR-X STRIPMAP IMAGE - 1 MAY 2012. TEST SITE-2 RESULTS ARE SHOWN IN D-F: D) WORLDVIEW-2 IMAGE, E) 1M TERRASAR-X SPOTLIGHT AND F) 3M TERRASAR-X STRIPMAP IMAGE, AND, G) WORLDVIEW-2 OVERVIEW IMAGE SHOWING THE TWO LOCATIONS OF 1000M X 1000M EACH IN BLACK AND CYAN BOXES.

For both subsets, TerraSARStripMap (Figures 4c and f) show a brighter canopy appearance than those of the TerraSARSpotLight image (b & e). There were no major radar shadows observed on the SAR images. Logging roads were faintly detected at both locations b and e which show lower backscatter effects: i.e., on the 1m TerraSARSpotLight of 7 March in 2012. The 1m TerraSAR-X SpotLight image has an incidence angle of 39^{o}. Logging roads were not detected on the 3m TerraSARStripMap of 1 May in 2012. This 3m TerraSARStripMap image has an incidence angle of 37.8^{o}. Although in general, the forest canopy appear coarse on both the TerraSARSpotLight and StripMap images but, that on the TerraSARStripMap image is less-coarse than the other; at both locations.

Discussion

Forest Degradation Phenomenon

The application of satellite and sensory technology has confirmed that degradation is ecosystem- and location-dependent in terms of parameters that might be measured such as particular species or certain forest goods. Stand-level assessments are required for local understanding, but the indicators must also be applicable for forest management units and at sub-national and national levels for international purposes [17]. Degraded forest issue should be seen as both state and a process as a continuum across time and/or space (i.e., the forest is being degraded; [18], [19]. Forest degradation must be measured against a desired baseline, and with understandable natural variation baseline. Fragmented forests are degraded because species may be lost and ecosystem processes may be altered or severely disrupted (e.g., [20]. Land-use change often leads to reduction in forest area and also do leave the remaining forest into patches that may continue to decrease in size over time[21], [22].Abundance of species, or groups of species, is commonly as an indicator for monitoring the effects and effectiveness of forest management [23][24], [25]. Many species are sensitive to forest degradation, and numerous examples are available of effects of forest change on species populations (e.g., [26] [27]).

Forest Degradation as a Result of Disturbances

Extensive unusual disturbances affect the capacity of a forest landscape to supply ecosystem services and reduce resistance to biotic and abiotic stresses (e.g., [28],[29], [30]). Forest ecosystems are continuously influenced by biotic and abiotic agents at all spatial scales (from individual trees to entire forest types), intensities of impact, and combinations of agents (for example, [31]). However, as long as these disturbances do not exceed the natural variation of an ecosystem over time, they will not cause long-term forest degradation (e.g., [32], [33], [34]).Human-caused fire is a major cause of forest degradation (for example, [35]), possibly exacerbated by climate warming (e.g., [36]). An unusual amount of fire can reduce the resilience of ecosystems, resulting in change or loss of ecosystem services [37]. Although fire is a natural element in many forest ecosystems, human activities have altered fire regimes across 60% of global terrestrial habitats [38]. Fire can be quantified by frequency and area burned using satellites that is to say forest degradation can be natural or unnatural occurrences. Soil erosion occurs as a forest degradation agent which occurs when wind and water translocation soil particles. Although some soil erosion is inevitable through normal precipitation and run-off, it is exacerbated by poor management practices such as inappropriate road placement or timber harvesting methods, especially in areas prone to soil movement such as steep slopes. Soils play key roles in forest biogeochemical cycles; erosion causes degradation through siltation of watersheds, reduced soil stability, and reduced fertility [39], [40], [41], [42], and increased rates of rainfall run-off [42].Protective functions refer to the intrinsic property of forest ecosystems to maintain soils, soil structure, quality, and moisture levels (e.g., [43]), which ultimately contribute to forest resilience. It has been reported that approximately 50% of global terrestrial carbon stocks reside in forest ecosystems as living and dead biomass and soil carbon [44], [45], and forests store an estimated 861 ± 66 Pg of carbon [46]. Forest degradation from unsustainable logging, fire, shifting cultivation, and other human-related disturbances can result in substantial reductions in carbon stocks and in the capacity for carbon storage (e.g., [9], [2006] 2009,[47].

Conclusions

The use of TerraSAR imagery at 1m and 3m was most effective in detecting both logging roads and clearcuts. From RADARSAT imagery of 8m resolution logging roads could not be detected, but the imagery did show clearcuts in smooth canopied forest.Generally, subset of forest indicators should further be assessed to determine forest degradation under a sustainable ecosystem management regime. The indicators were remotely sensed though further calibration of the ground work and aggregated stand to management unit or landscape levels need to be conducted at national scales. However, degradation is a continuum of decline in ecosystem goods and services from primary forest to deforested lands. It is therefore identified that forest degradation is a topic of global concern because of the loss of goods and services which multi-dimensional management approach should be encouraged.

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